

INTERLOCKING SCHEDULES OF REINFORCEMENT¹

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Four male pigmented rats were exposed to a procedure designed to investigate the relation between several performance measures and a schedule continuum ranging from FR 36 to FI 2 through four intermediate interlocking schedules. On all schedules, each subject developed a stable performance that was generally break-and-run. Analysis of the cumulative records, post-S^B breaks, and running rates showed a continuum of performance related to the schedule continuum.

In interlocking schedules of reinforcement, the number of responses required to establish the reinforcing contingency is some function of time since the preceding reinforcement. In the simplest case, the response requirement decreases as a linear function of time, and the subject may receive reinforcement either after a short delay by working at a high rate, or for a single response by waiting until the contingency has been established, or for any intermediate performance. Thus, the interlocking schedule has features intermediate between the fixed-ratio schedule, in which the response requirement is constant and reinforcement frequency dependent upon response rate, and the fixed-interval schedule, in which frequency of reinforcement is approximately the same for a wide range of rates.

Figure 1 shows the interrelations of the fixed-ratio, interlocking, and fixed-interval schedules in the diagrammatic notation suggested by Skinner (1958). The two parameters defining an interlocking schedule are the response base (the response requirement at

$t = 0$) and the time base (the time at which the contingency is established if no responses have been made). If the time base of 1c is increased, as in 1b, the schedule approaches fixed ratio (1a). Similarly, if the response base is increased (1d), the schedule approaches fixed interval (1e).

Although the time and response parameters clearly define a continuum of the experimental independent variables ranging from fixed ratio to fixed interval through the interlocking schedules, the possible nature of an associated performance continuum is an open question. Performances at the fixed-ratio and fixed-interval ends of this continuum have been studied extensively, but the generic features of "fixed-interval" and "fixed-ratio" behavior are still in doubt. This is particularly apparent in fixed-interval performances: not only is there variability at any stage of training (Ferster & Skinner, 1957), but the general nature of the performance also changes with prolonged exposure to the schedule (Cumming & Schoenfeld, 1958; Sherman, 1959).

This study reports changes in several dimensions of performance as related to the parameters of the schedule continuum.

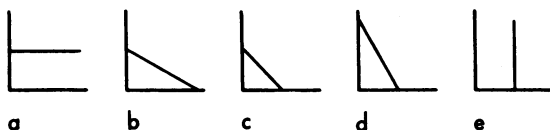


Fig. 1. Diagrams of fixed-ratio, interlocking, and fixed-interval schedules of reinforcement.

¹This investigation was carried out at Columbia University with support from research grants M-1421 and MY-3673, from the National Institute of Mental Health, U.S. Public Health Service.

METHOD

Subjects

The subjects were four male Harvard-strain pigmented rats, about 1 year old at the start of experimentation. All four animals had had prior water magazine training, but none had a history of lever pressing.

Apparatus

The programming device consisted of a ratchet stepping mechanism and a synchronous motor individually attached to a concentric double shaft. Rotating contact arms were attached to each of the two shafts, such that one was driven clockwise by the motor while the other was moved counterclockwise by the stepping mechanism. Associated relay circuitry established the reinforcing contingency when the arms made contact, and simultaneously stopped the motor. The next response produced reinforcement and the motor was once more started, initiating a new schedule cycle. An advantage of this programming device is that no reset is required after reinforcement, since the time and response contact arms always start in the same position relative to one another. The time base of the schedule can be altered readily by changing the speed of the motor, whereas other response bases can be established by frequency division of the input to the stepping mechanism. Obviously, if the motor is turned off, a fixed-ratio schedule is in effect; if the response input is disconnected, a fixed interval prevails.

The response chamber used was sound-proofed and totally unilluminated; it was equipped with a single lever and a dipper mechanism for the delivery of water reinforcements.

Procedure

All subjects were pretrained with continuous reinforcement. Rats 1, 3, and 4 acquired lever pressing without intervention; Rat 2 required some shaping before the response was established. Each rat was given six 1-hr sessions of continuous reinforcement on successive days, with access to water for 7 min at the end of each session. The subjects were then placed directly on a linear interlocking schedule of 2 min and 36 responses (hereafter abbreviated as INT 2/36) and run for approximately 1 hr daily for 40 consecutive days.

Subsequently, all animals were exposed to the following sequence of schedules: INT 2/72, INT 4/72, INT 4/36, FR 36, and FI 2. Two extinction sessions were given between successive schedules.

After 25 consecutive days of running on INT 2/72, subjects were run 5 days per week. Since this produced no apparent changes in

daily variability, this procedure was maintained throughout the remainder of the experiment.

Interlocking schedules were changed after 40 days, except that Rat 4 required 7 additional days on INT 4/36 before its performance was considered stable. The criterion for stability was the apparent absence of systematic changes in performance for 8 days.

Determinations for FR 36 and FI 2 were carried out in the same way, except that the amount of schedule exposure required to produce stability varied. Rats 1 and 3 needed only 12 days of FR 36, whereas Rats 2 and 4 needed 40 days. All subjects became stable in 40 days on the FI 2 schedule except Rat 3, which required 53 days.

Each day's session began with a reinforcement available, so that the first response was always reinforced. The session was terminated with the first reinforcement occurring after 1 hr. Subjects were then given access to water in their home cages for 7 min, with food always available. Sessions were run at approximately the same time daily.

Cumulative records were taken of each session. In addition, the duration of the postreinforcement break (PRB) and the number of responses per reinforcement was recorded after each reinforcement. The average error in recording the PRB's was 0.5 sec. If the subject continued to respond after the delivery of reinforcement, responses occurring within 2 sec were not counted in order to prevent the recording of spuriously short PRB's. In all cases, the first reinforcement was excluded from data analysis, since it was available at the start of each session.

RESULTS AND DISCUSSION

In addition to the presentation of cumulative records, the subjects' schedule performances will be analyzed in terms of two major measures: the PRB, and the running rate. The latter measure may be calculated in two ways: (1) by determining the running rates for each individual cycle throughout a session, and then averaging; and (2) by dividing the total number of responses in a session by the difference between the session length and the sum of the PRB's. Comparison of these two methods indicated no significant difference; accordingly, the second method was used.

RAT-1

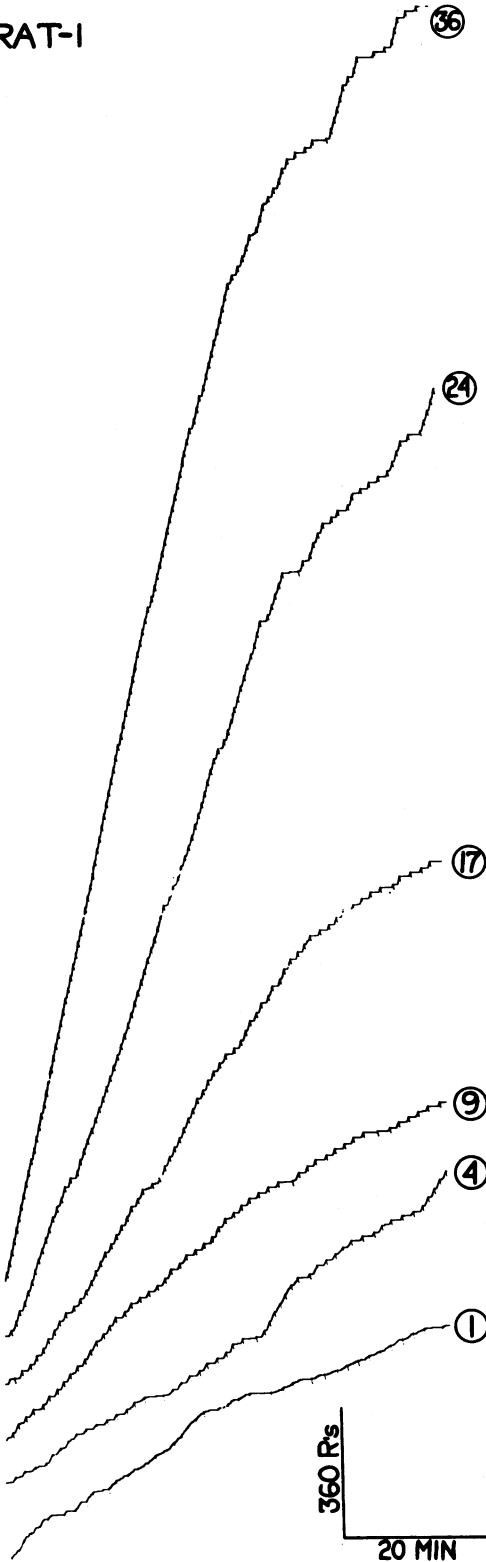


Fig. 2. Selected cumulative records for Rat 1. Session number is shown after each record.

RAT-2

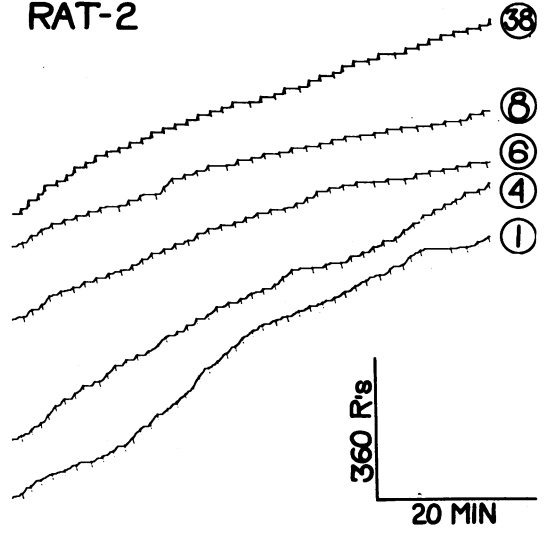


Fig. 3. Selected cumulative records for Rat 2. Session number is shown after each record.

RAT-3

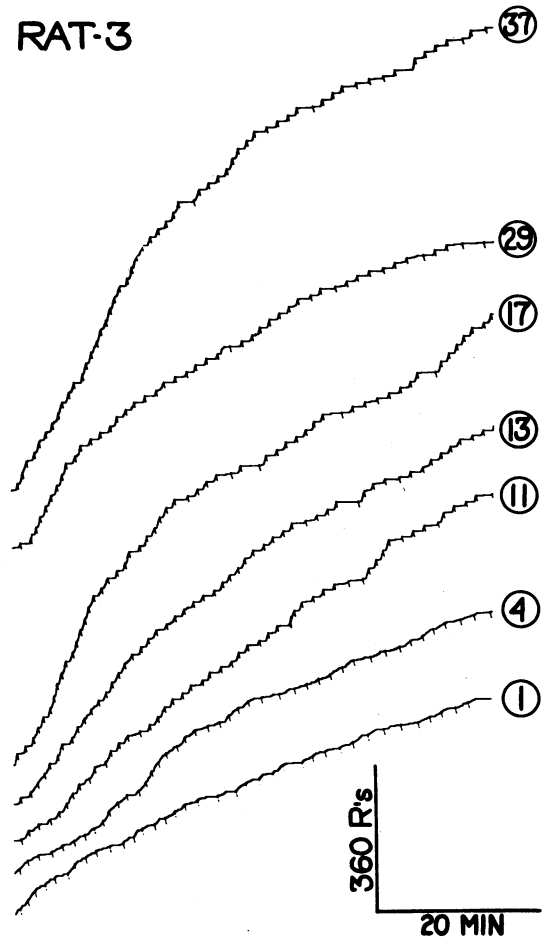


Fig. 4. Selected cumulative records for Rat 3. Session number is shown after each record.

Other studies have shown these measures to be useful in characterizing schedule performances. They have been applied to FR by Boren (1953) and by Ferster and Skinner (1957), and to FI (after prolonged exposure) by Cumming and Schoenfeld (1958) and by Sherman (1959).

Figures 2 through 5 show the performances of the four subjects on INT 2/36 as cumulative-response curves. The successive 1-hr records are arbitrarily displaced in the vertical.

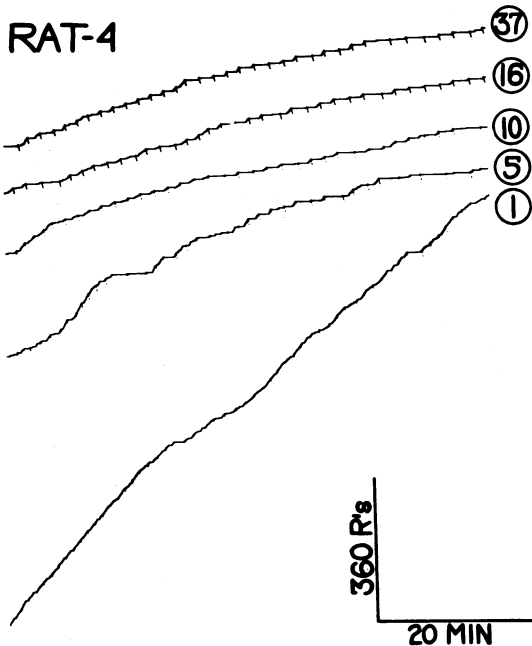


Fig. 5. Selected cumulative records for Rat 4. Session number is shown after each record.

Session 1, representing the transition from continuous reinforcement to INT 2/36, is shown for all subjects. The uppermost record in each figure is representative of the animals' performances near the end of the 40-day experimental period; others were selected to show successive stages in the development of the final performance.

Apart from some differences in overall rate, the Day 1 records (representing the transition from continuous reinforcement to INT 2/36) are quite similar, with all subjects maintaining a reasonable steady rate.

In Subject 1, a break-and-run pattern emerged by the 4th session; runs with every short PRB's often continued through five or six cycles. By the 9th session, clear break-and-

run behavior was evident, with the PRB averaging about one-half the cycle length. Thereafter, the overall rate increased slowly but consistently from day to day until about the 27th session. A high, relatively stable rate was then maintained until the 40th day. Almost all variability of performance occurred in the last 20 min of a session, as the record for Day 36 indicates. After a long, steady, initial segment in which the PRB's averaged 5 sec, occasional long PRB's appeared; but the running rate remained approximately constant at 108 R's/min. The time within a session at which this change appeared is the only variable aspect of this animal's performance over the last 10 days.

Subject 2 began to exhibit long PRB's by the second 30 min of the 4th session, and these were well established in Session 6. Late in Session 8, PRB's lengthened to about 75 per cent of the cycle length. This pattern was maintained to the 40th day substantially unchanged, except for a slight increase in overall rate up to the 30th day. Cumulative records for the last 10 sessions could be superimposed with evidence of only very slight local irregularities. At this point the PRB averaged 70 sec and the running rate 50 R's/min.

Rat 3 showed relatively little change from Sessions 1 to 4. By Day 11, long PRB's had become characteristic of the last part of the session. On Day 13, most intervals had a break-and-run character. A high rate at the start of the session emerged on Day 17. In general, PRB's lengthened throughout a session, whereas running rates remained constant. The animal worked at an unusually low overall rate on Day 29, but the pattern of progressively lengthening PRB's remained. Session 37 is typical of this subject's performance over the last 8 days, with the PRB averaging 39 sec and the running rate 51 R's/min.

The record on Day 1 for Rat 4 was similar in form to the other animals' records, but the overall rate for this rat was twice that of the other subjects. In spite of this high initial rate, this subject decelerated gradually during the next four sessions. Some long PRB's appeared in the 5th session, and by the 10th session, a pattern of long PRB's followed by a low rate run emerged. From Day 10 to Day 40, there were virtually no further changes in this

subject's performance. For this period, the mean PRB was 72 sec and the mean running rate was 16 R's/min.

The acquisition records in Fig. 2 to 5 reveal no relationship between overall rate on Day 1 and the final stable rate on INT 2/36. Because of the large individual differences observed in acquisition, data from all schedules will be presented and discussed for individual subjects.

Figure 6 presents cumulative records for complete sessions representative of the final performances of Rat 1 under each schedule. The top two records are for INT 2/36 and INT 4/72, schedules for which the contingency functions are parallel. Reading down the left column, the time base increases to 4 min in INT 4/36, and becomes infinite for FR 36. In the right column, we move to FI 2 by way of the intermediate interlocking schedule, INT 2/72.

The left column records show a general increase in overall rate as the schedules ap-

proach FR, whereas the right column records show a decrease as FI is approached. The overall rate for INT 4/72 is slightly higher than that for INT 2/36. This difference is not obvious on the cumulative records, but is shown by the numerical data on responses per session in Table 1. Thus, for this animal there does appear to be a continuum along which overall rate is related to the schedule parameters.

Inspection of Fig. 7, 8, and 9 shows that the same relations hold for the schedule performances of the remaining subjects, except for the FI case. Here, the overall rates were higher than they were on INT 2/72. Evidence that it is difficult or impossible to recover low rate performances after exposure to schedules generating high rates (Boren, 1953; Cumming & Schoenfeld, 1959) may account for this apparent exception to the notion that overall rates decrease as the schedule approaches FI.

Table 1 gives mean running rates and PRB's for all subjects. Inspection of this data shows

Table 1
Some Measures of Performance on Four Interlocking Schedules of Reinforcement, FR 36, and FI 2.
Values are Means for the Final 8 Days of Exposure to Each Schedule.

<i>Schedule</i>	<i>Rat</i>	<i>Resp/hr</i>	<i>Reinf/hr</i>	<i>PRB (sec)</i>	<i>Range of PRB's (daily)</i>	<i>Running Rate- Resp/min</i>
INT 2/36	1	3842	136	10.8	7.1-16.8	108.0
	2	497	43	70.1	67.0-73.5	50.9
	3	1103	60	38.7	35.2-40.6	51.8
	4	286	35	72.2	62.5-85.2	16.0
INT 2/72	1	2318	62	30.4	25.8-32.0	81.0
	2	531	38	82.9	77.5-90.6	70.8
	3	950	44	56.5	51.9-63.1	51.0
	4	438	35	70.6	62.1-85.2	23.4
INT 4/72	1	4143	73	23.2	17.6-26.9	130.2
	2	809	26	110.4	97.1-120.8	66.6
	3	1636	38	57.7	51.1-70.0	69.6
	4	756	26	76.1	67.3-88.2	28.2
INT 4/36	1	6095	184	7.4	6.1-8.3	163.2
	2	2598	86	28.6	20.4-38.7	136.8
	3	8186	249	4.6	4.4-5.0	199.2
	4	1326	51	31.0	26.4-34.1	39.6
FR 36	1	6586	178	6.9	5.3-9.2	166.2
	2	2627	71	34.8	26.7-47.4	139.8
	3	10508	284	4.2	2.9-4.8	262.2
	4	3850	104	11.0	8.4-14.8	94.2
FI 2	1	919	30	67.1	59.8-71.9	34.7
	2	1135	30	84.6	81.0-88.5	64.2
	3	1145	30	52.8	33.6-65.2	34.1
	4	1266	30	50.1	46.9-56.0	36.2

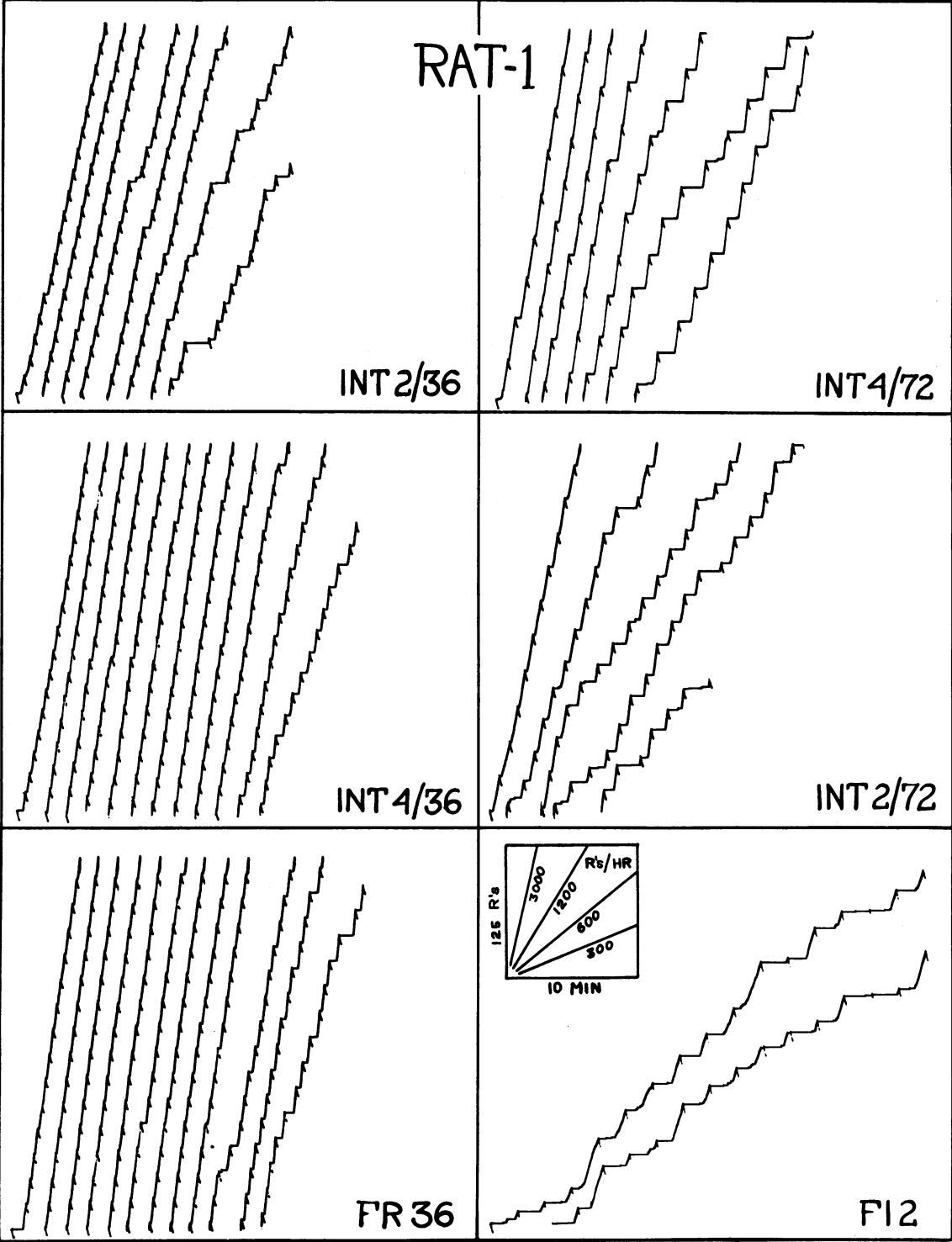


Fig. 6. Cumulative records representative of stable performance on six schedules for Rat 1. Each record is for a complete session.

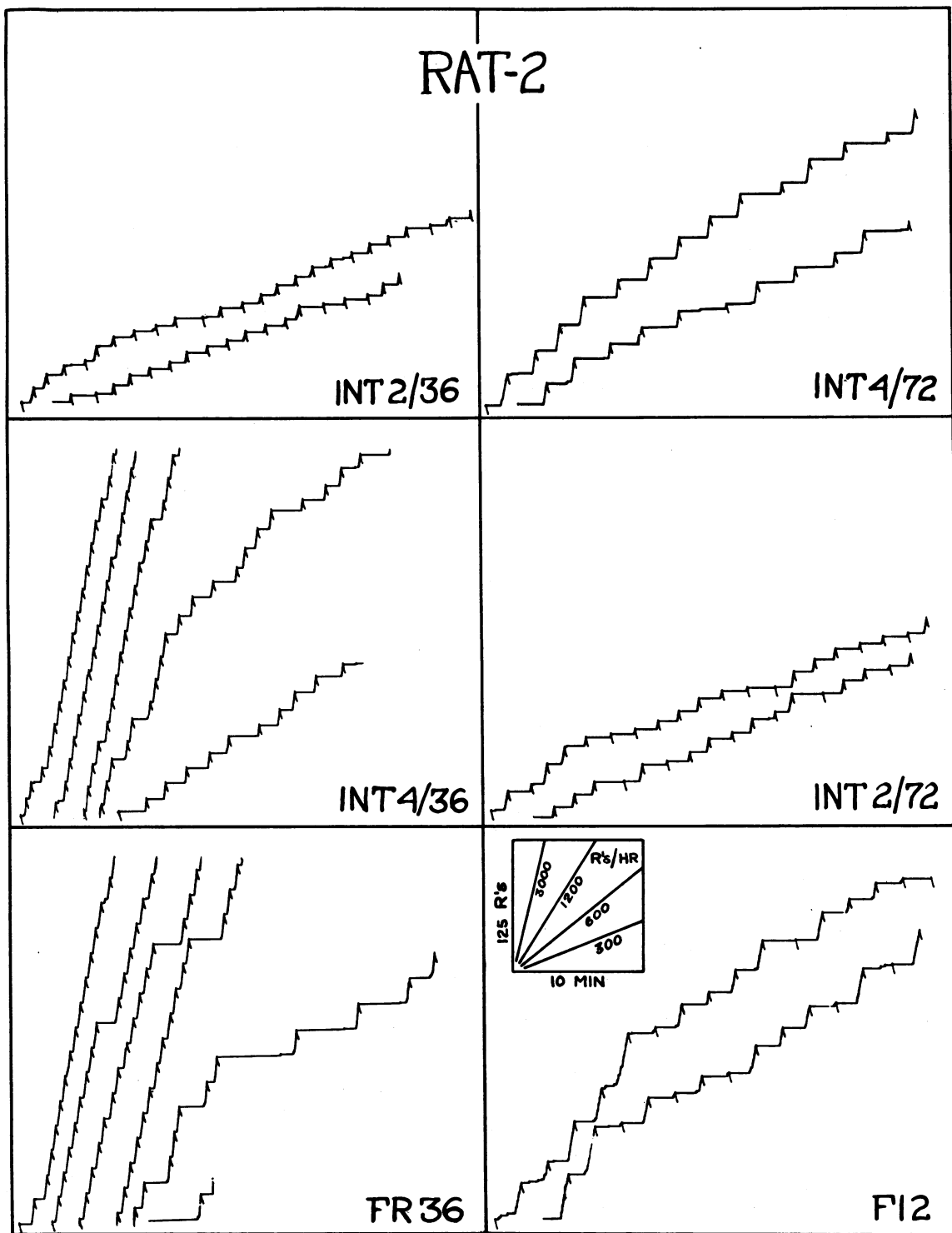


Fig. 7. Cumulative records representative of stable performance on six schedules for Rat 2. Each record is for a complete session.

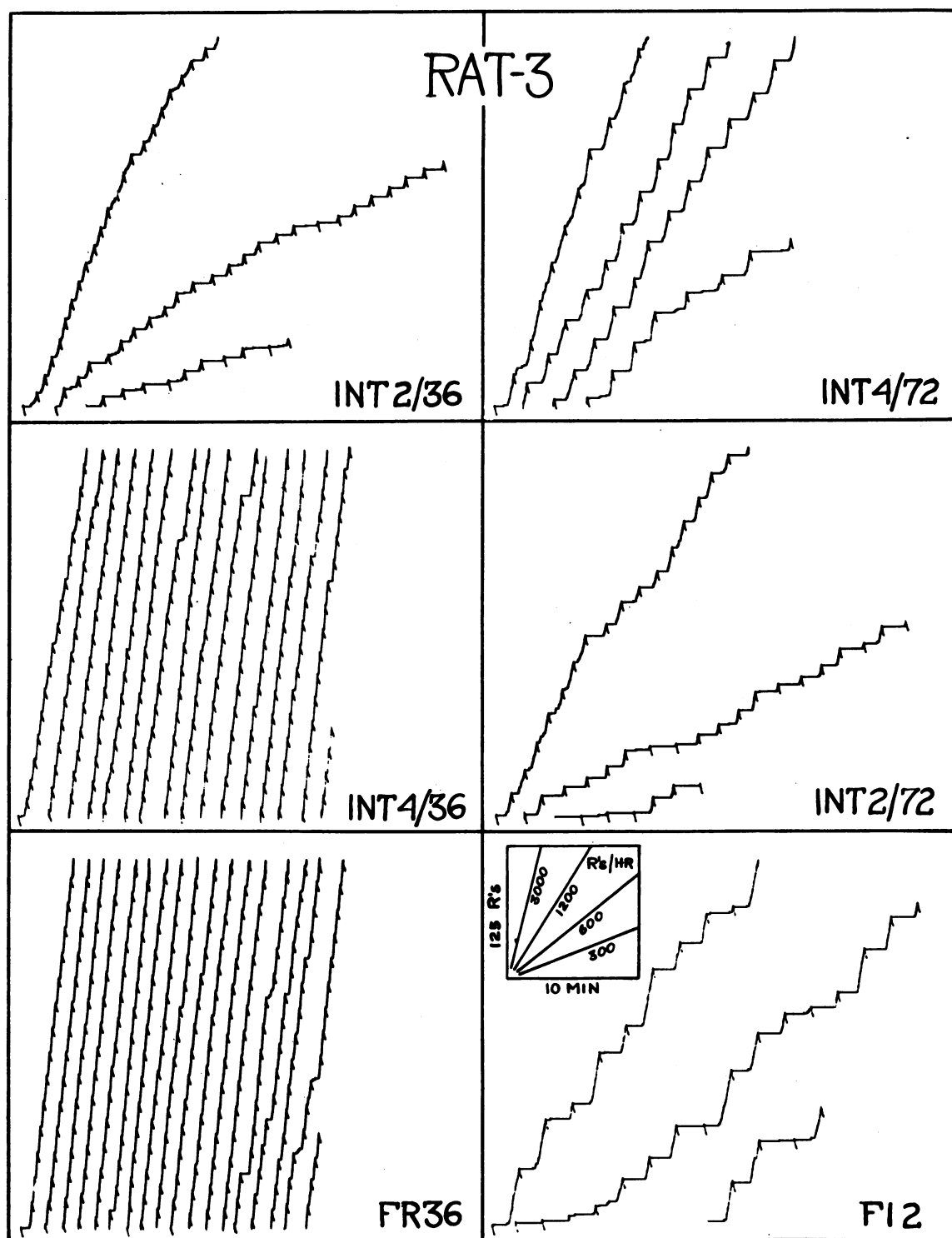


Fig. 8. Cumulative records representative of stable performance on six schedules for Rat 3. Each record is for a complete session.

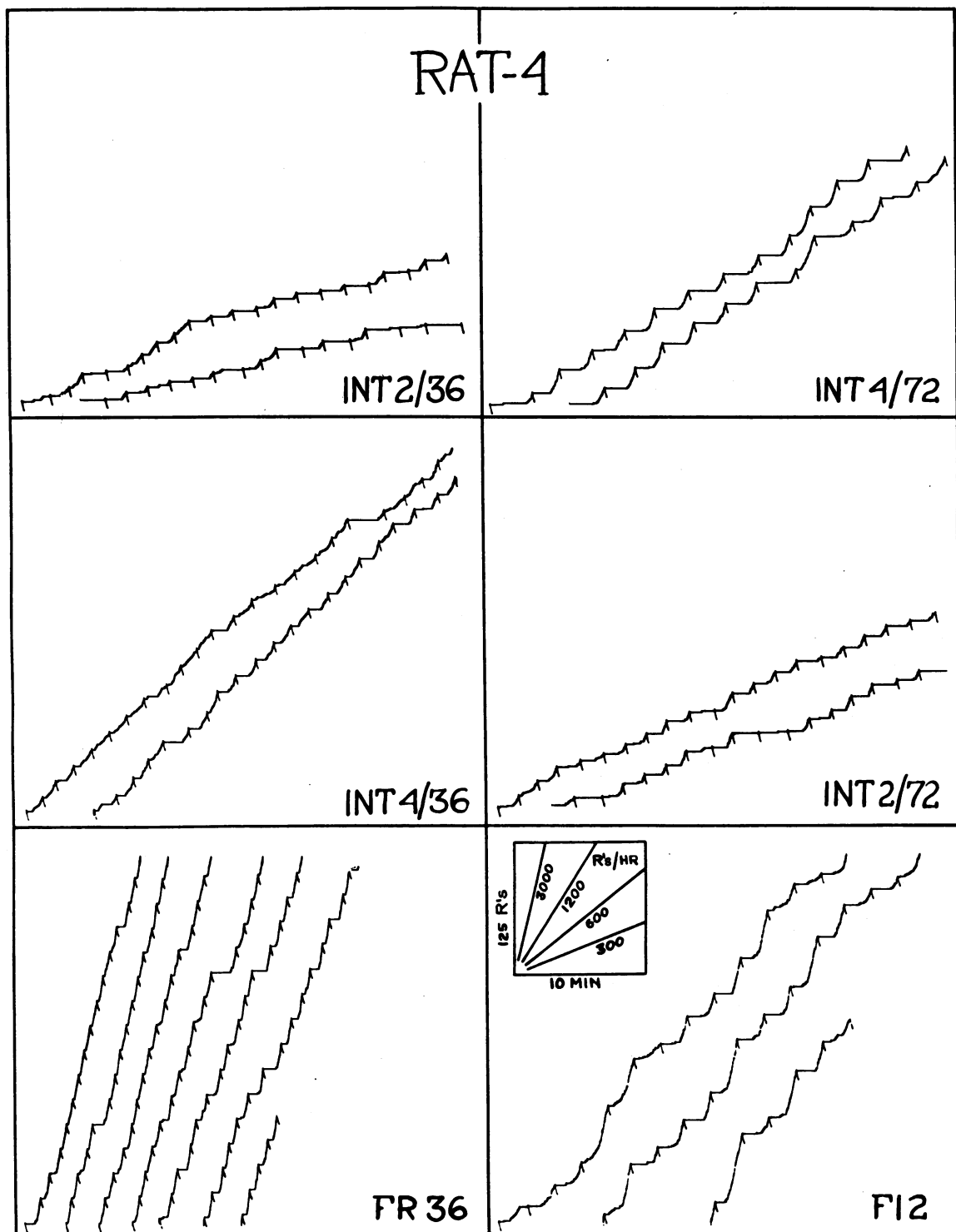


Fig. 9. Cumulative records representative of stable performance on six schedules for Rat 4. Each record is for a complete session.

that when the response base is increased, the running rate tends to decrease and the PRB tends to increase. When the time base is increased, running rates increase and PRB's decrease. When both response and time bases are increased, as in the change from INT 2/36 to INT 4/72, both running rate and PRB increase. The directions of these changes bear out the relation of performance measures to the schedule continuum shown by the cumulative kymograph records.

Both the running rate and PRB data indicate that when one of the schedules chosen for comparison is INT 2/72, the performance changes are less orderly. This may be accounted for by the differential effects of various schedules of reinforcement on variations in PRB and running rate. It can be shown that the cycle length (time between reinforcements) depends upon the schedule parameters and these performance measures according to the following expression:

$$T = T_1(R_1 + \text{PRB} \cdot r) / (R_1 + T_1 \cdot r)$$

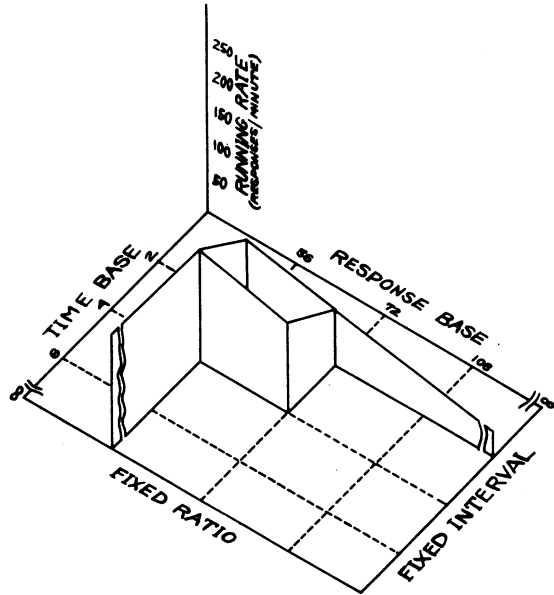
where T represents the cycle length, T_1 the time base, R_1 the response base, PRB the post- S^R break, and r the running rate. It will be observed that as R_1 approaches infinity (the fixed-interval case), the cycle length becomes independent of performance and approaches T_1 . If the expression is rewritten in the form

$$T = (R_1 + \text{PRB} \cdot r) / (R_1/T_1 + r)$$

it becomes evident that as T_1 approaches infinity (fixed ratio), the cycle length is inversely related to running rate, and directly related to the PRB, for a given response base. Thus, changes in performance will produce far larger changes in reinforcement frequency on schedules at the ratio end of the continuum than at the interval end.

Therefore, to the extent that changes in behavior may be dependent upon a discriminable change in reinforcement frequency, one may expect that performance on schedules approaching FI will be less influenced by schedule parameters than by other variables, such as conditioning history on earlier schedules.

Because interlocking schedules are defined by two independent parameters, they cannot be represented on a single axis. Figure 10 was prepared to display the relations of all schedules at once. This figure is a three-



as the schedule approaches FI. One apparent individual exception to this is the performance of Rat 2 on FR 36. Figure 7 shows that late in the session, PRB's become very long and are sometimes terminated by a probe rather than a run. This ratio straining is absent from the performance of this subject on the adjacent schedule INT 4/36, perhaps as a consequence of the "adjusting" feature of interlocking schedules. The absence of similar probing behavior on FR 36 for the other subjects may simply be due to the difficulty of identifying probes on cumulative records when PRB's are short and running rates high. Analysis of probe frequency in relation to the schedule continuum might well come with a definition of a probe as some deviation from the mean of the IRT distribution for a given ordinal position within the run.

In this experiment, all subjects were exposed to all parameter values in the same sequence. This design assumes that the effects of a given schedule will be greater than the effects of cumulative exposure to the general situation. The change to be expected from continued exposure is a slow but systematic increase in rate. Analysis of our data shows that although such a trend may be present, the introduction of each new schedule in general produces an immediate rate change which is outside the range of variability observed on the preceding

schedule. Exceptions were noted for Rat 4, whose transitions from INT 4/72 to INT 4/36, and from INT 4/36 to FR 36, showed slow increases. However, this subject had not shown increases in rate on previous schedules. Accordingly, although there is evidence for some changes that are due to continued exposure alone, the major alterations in performance can be assigned to schedule variables.

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Received July 15, 1961